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FILTER STABILITY TESTS ON
MUD MOUNTAIN DAM TRANSITION AND CORE MATERIAL

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Waterways Experiment Station
Vicksburg, Mississippi

29 December 1947

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FILTER STABILITY TESTS ON MUD MOUNTAIN DAM TRANSITION AND CORE MATERIAL

Introduction

1. This report presents the results of filter stability tests on transition and core materials for Mud Mountain Dam performed by the Waterways Experiment Station, Vicksburg, Mississippi. These tests were authorized by the Office, Chief of Engineers in February 1942 and were conducted in accordance with instructions outlined in a letter from the Office, Chief of Engineers to the Waterways Experiment Station, dated 10 February 1942.

General information

2. Mud Mountain Dam, located on the White River in the State of Washington, is a rock-fill dam approximately 425 ft high with an impervious rolled-earth core. It is one of the major units in the Puyallup River Flood Control Project, built for the protection of Tacoma and vicinity. A typical cross-section of this dam is shown in plate 1. The core material, Zone 2, is a mixture of approximately 30 per cent glacial till and 70 per cent stream sand and gravel, with sizes ranging up to 6 in. in diameter. This core is separated on either side from the rock-fill sections (Zones 1 and 3) by a transition material consisting of crushed rock. The grain-size distribution curves of the core and transition materials are shown on plate 2, with sizes between 3- and 6 in.

having been removed for testing purposes prior to receipt. Curves 1, 2 and 3 represent the finest, average, and coarsest gradations, respectively, of the transition material.

3. The initial investigation of the effectiveness of this crushed rock as a transition material between the core and shell zones of Mud Mountain Dam is covered in a report by the Seattle District Soils Laboratory, titled "Transition Material, Mud Mountain Dam," dated 23 September 1941. It was concluded in the report that the transition material was not a satisfactory filter as placed, but that the core material was inherently stable within itself. The Office, Chief of Engineers, in the review of this report, in December 1941, concurred with the opinion of the District Engineer, Seattle District, and the Division Engineer, North Pacific Division, that the embankment was safe against piping, but requested the Seattle District to check the validity of the statement in the laboratory report, " ... Thus, the transition material is not a satisfactory material as placed ... " by running conventional filter tests to failure on samples of the core and transition contact materials. The Seattle District was further instructed to send sufficient materials to the Waterways Experiment Station for a complete series of filter tests.

Purpose

4. The purpose of these tests was to determine whether the transition material as placed would act as a perfect filter, in that it would be considerably more pervious than the core, and yet completely retain the core in place.

Tests performed

5. Three tests were recommended by the Office, Chief of Engineers, one of each on the following combinations of materials, (shown on plate 2) which are representative of those used in construction, with each material compacted to its maximum density.

- a. Average core material (2) against average transition material (4).
- b. Finest core material (1) against coarsest transition material (5).
- c. Coarsest core material (3) against coarsest transition material (5).

One test under condition a was performed by the Experiment Station in 1942 and then further testing was discontinued due to the war. One test similar to condition b was performed by the Experiment Station in 1946. No test has been performed under condition c, for reasons explained in a succeeding paragraph. The following paragraphs contain a brief discussion of the tests performed.

Test 1 - Average Core Material Against Average Transition Material

Apparatus

6. The apparatus used consisted of a steel permeameter 3.5 ft high with piezometer tubes mounted at intervals along the side to measure loss in head through the core and transition. The permeameter had an inside diameter of 15 in. A perforated plate with 3/16-in. openings was placed approximately 8 in. from the bottom of the permeameter with a catch basin underneath.

Materials used

7. The core material and transition material were screened and recombined in order to obtain the exact gradation specified. As given in the Mud Mountain Dam laboratory report previously referred to, the transition material (plate 3, curve 4) will compact to an average dry density of 120 lb per cu ft, and as given in letter from the Seattle District, dated 12 May 1942, the average dry density of the core material (plate 3, curve 2) for the first fifteen weeks of operation was 128.8 lb per cu ft; the optimum water content for the core material was 16.5 per cent.

Loading transition material

8. The transition material was first loaded directly on the perforated plate in five equal layers, each layer being tamped under water so as to result in a total thickness of 1.25 ft at a dry density of 120 lb per cu ft. In loading the transition material, a certain amount of material passed through the 3/16-in. perforations in the base plate and into the catch basin. After loading, the water level in the permeameter was raised to 2.0 ft above the top of the transition material. This head was maintained for approximately one hour, with the flow downward through the transition material. This was done in order to remove any particles in the transition that might be carried through under this condition of flow. This resulted in a total of 1.3 per cent (1085 grams) of the transition material passing through the 3/16-in. perforations of the base plate during loading and under the above condition of flow. The gradation of the material passing through the base plate perforations is

shown on plate 3, curve A. The same procedure was duplicated for another hour, and this time the water passing through the transition material was clear and no material was deposited in the catch basin. The water level was not allowed to drop below the top of the transition material at any time.

Loading core material

9. The core material was divided into five equal parts by weight. Each part was mixed at the optimum water content (16.5 per cent) and compacted on top of the transition material to a thickness of 0.25 ft before adding the next layer. This was done in order to get uniform compaction to the desired density of 128.8 lb per cu ft. The total thickness of compacted core was 1.25 ft. The core was then saturated slowly by allowing water to flow upward through the transition material.

Test procedure and data secured

10. Flow was directed downward through the core and transition at various constant heads of water. These heads ranged from 0.7 to 10.0 ft. Heads up to 6.25 ft were maintained by gravity flow, using a variable headwater and tailwater setup. Air pressure was used to obtain higher heads. Periodic measurements of the quantity of water flowing through were made under each constant head. The coefficient of permeability and hydraulic gradients were computed, based on the thickness of the core alone, since the transition was so pervious that practically no head loss occurred. At the end of each run under a given head, the material which had passed through the perforated plate was collected, weighed, and its gradation determined.

Results of test

11. A summary of the results of this test is shown on table 1. It can be seen that, in general, the quantity of flow in cubic centimeters per minute remained about constant with time for any given head. The coefficient of permeability of the core material increased with an increase in hydraulic gradient up to a gradient of 3.0, and then remained practically constant up to a gradient of 8.0. This indicates that some fines in the core material may have been moved into the transition material during the first part of the test, thus causing the increase in permeability, and that the material became stable under a gradient of 3.0, as no further increase in permeability occurred. Only a very small amount of material washed through the perforated plate during this test. The weights of material washed out are listed in table 1, and the gradation curves (identified by the letters B through F) are shown on plate 3.

Test 2 - Processed Core Material Against Coarsest Transition Material

General

12. This test corresponds to test b suggested by the Office, Chief of Engineers. However, because of the satisfactory performance of the materials in the previous test, it was decided to modify test b and develop an extreme condition. Therefore, only that portion of the finest core material passing the No. 4 sieve was used. It was considered that this produced a more critical combination of materials than that of the entire gradation of the core against the transition material.

Apparatus

13. For this test a transparent permeameter was used, so that the movement or deposition of material could be observed. The permeameter had an inside diameter of 8 in. and a base plate having 3/16-in. openings. Water was supplied by a constant head tank.

Materials used

14. The transition material was the coarsest gradation furnished and is shown as curve 5 on plate 4. The finest gradation of core material, shown as curve 1 on plate 2, was processed as explained above, and the grain size curve of this processed core material is shown as curve 6 on plate 4.

Loading the materials

15. The transition material was rodded into the permeameter under water to a thickness of 7 in. at a dry density of approximately 114 lb per cu ft. Water was then allowed to flow through until clear. Then 4000 grams of the processed core material were puddled evenly over the surface of the transition material by tamping lightly under water. This resulted in a layer of core material in a very loose state 2 in. thick above the transition material. No density determination could be made on the core material, because some of the fines penetrated down into the transition material while loading.

Test procedure and data obtained

16. The flow was directed downward through the core and transition materials under a head of 0.63 ft. During this condition of flow, core

material was observed moving into the upper part of the transition, penetrating to a depth of approximately 2 in. This head was maintained for two hours, when no further movement of core material was visible. During the two hours of flow, the core material above the transition decreased in height from 2.0 in. to 0.75 in. The head was then increased to 1 ft and the same procedure followed. This resulted in a decrease in height of core material above the transition to 0.25 in. At this stage of the test, 2000 grams additional of core material were added to the existing core, bringing the height of the core material up to 1.25 in. above the top of the transition. The head was then increased in increments up to a head of 6 ft. No further movement of core material was observed. At this stage of the test, 2000 additional grams of core material were added and the flow continued under a head of 6 ft. The quantity of water flowing through the core and transition was measured at intervals under each condition of flow. No permeability values are reported, as it was impossible to determine the exact hydraulic gradient through the core, due to the uncertain height of sample. The material passing through the perforated plate was collected after each condition of flow, weighed, and its gradation determined. Since the penetration of the core had taken place visibly within the top 2 in. of the transition, the gradation of the transition at the end of test was determined separately for the bottom 5 in. and the top 2 in.

Results of test

17. A summary of the results of this test is shown on table 2, from which it can be seen that the transition material was much more pervious than the core material, as the flow was greatly reduced by the addition of core material. Under a head of 0.63 ft, 6 per cent (234 grams) of the core material was washed through the transition. After increasing the head to 1 ft, an additional 69 grams of core material was washed through the transition, making a total loss of 7.6 per cent of the core material. During this time, core material was penetrating into the upper part of the transition material and forming a filter. Penetration was visible for a depth of 2.0 in. into the transition. This resulted in a reduction in height of the core material above the transition of from 2 in. to 0.25 in. After adding additional core material, the transition tended to stabilize under a head of 1.5 ft. During the first three hours of flow under this head, 61 grams of material washed through the transition, which resulted in an increase in the rate of flow. However, after 40 hours of flow the rate remained about constant. No further reduction in the height of core material above the transition occurred. After adding the third layer of core material, the rate of flow decreased from 11 cubic centimeters per minute after 15 hours of flow to 3.8 cubic centimeters per minute after 128 hours of flow. This decrease was probably due to consolidation in the core material. However, no measurable decrease in height occurred.

18. The gradation of the material passing through the perforated base plate is shown on plate 4 and identified by the letters G through

L, as shown on table 2. The gradations of the bottom 5 in. and top 2 in. of the transition material after test are shown on plate 4 and identified by the letters M and N, respectively.

19. Because of the satisfactory performance of the transition material in this test and the fact that the test was more severe than any of the tests originally scheduled, it was not considered advisable or necessary to run test c, described in paragraph 5. It was decided, however, to check the internal stability of the core and transition materials independently.

Stability test on
coarsest core material

20. For this test, the transparent permeameter described in paragraph 13 was used. The coarsest gradation core material (which is shown as curve 3 on plate 2) was placed in the permeameter at a dry density of 132 lb per cu ft. Under a hydraulic gradient of 3.3 there was no material washed through the sample for a period of 96 hours. Approximately two gallons of water passed through the sample. It is evident that, insofar as the internal stability is concerned, the core material at maximum density is a satisfactory material.

Stability test on
coarsest transition material

21. The coarsest transition material (which is shown as curve 5 on plate 2) was placed in the transparent permeameter at a dry density of 118 lb per cu ft. A total of 38.1 lb of material was used in the test. The sample was completely pervious and no head could be maintained. Under flow of water, a large proportion of the fine material washed

through immediately. The test was continued until no more fines were present in the discharge and the sample was in a stable condition. The total quantity of fines washed through was approximately one lb. These results indicate that the transition material would be unsuitable as a filter material. However, the conditions imposed by this test are not truly representative of the existing conditions, and it should be noted that test 1 and test 2 approximate actual conditions much more closely than the tests on the materials taken independently.

Conclusions

22. Based on the data presented in this report, the following conclusions appear to be warranted:

- a. For the average core material against the average transition material, both compacted to their maximum density, the transition was many times more pervious than the core; however, it completely retained the core.
- b. For the finest processed core against the coarsest transition material, where the materials were placed in a rather loose state, 7.6 per cent of the core material washed through the transition before a satisfactory filter was formed. However, due to fines from the core material penetrating into the voids of the transition, a satisfactory filter was formed in a relatively short time.

TABLES

TABLE 1

Waterways Experiment Station
Filter Stability Tests, Mud Mountain Dam

SUMMARY OF TEST 1: AVERAGE CORE AGAINST AVERAGE TRANSITION

Effective Head in Feet	Hydraulic Gradient through Core	Cumulative Time of Flow in Hours	Quantity in Cc per Min.	Coefficient of Permeability 10^{-4} Cm/Sec	Material Washed Out Weight in Grams	M.A. Fig. ⁴ Curve No.
0.70	0.56	3	0.22	0.05		
		5	0.19	0.04		
		7	0.24	0.06		
		23	0.19	0.04	39	B
1.25	1.00	2	0.30	0.04		
		3	0.30	0.04		
		20	0.29	0.04		
		44	0.44	0.06	131	C
2.50	2.00	5	0.62	0.04		
		45	1.25	0.08		
		52	1.34	0.09		
		68	1.39	0.09		
		73	1.51	0.10		
		92	1.54	0.10		
		140	1.56	0.10	30	D
3.75	3.00	4	3.06	0.14		
		22	2.90	0.13		
		51	2.90	0.13		
		69	2.95	0.13	0	-
		117	2.95	0.13		
5.00	4.00	5	4.18	0.14		
		21	4.28	0.14		
		46	4.43	0.14		
		70	4.06	0.13		
		99	3.52	0.12	14	E
		117	3.48	0.11		
6.25	5.00	6	4.93	0.13		
		23	4.76	0.12		
		47	4.45	0.12	12	F
		70	4.05	0.11		
7.50	6.00	8	4.09	0.09		
		17	3.31	0.07		
		28	3.45	0.08		
		36	3.53	0.08	8	-
8.75	7.00	1	4.29	0.09		
		4	5.54	0.12		
		8	5.05	0.11		
		11	5.06	0.11	0	-
10.00	8.00	1	5.65	0.10	0	-
		5	5.48	0.10		
		8	5.45	0.10	0	-

Notes:

Core material used in test = 197 lb. Height of sample = 1.25 ft. Dry density = 128.8 lb/cu ft.
 Transition material used in test = 184 lb. Height of sample = 1.25 ft. Dry density = 120 lb/cu ft.
 All permeability measurements shown above are for flow through core only.

TABLE 2

Waterways Experiment Station
Filter Stability Tests, Mud Mountain Dam

SUMMARY OF TEST 2: PROCESSED CORE MATERIAL AGAINST COARSEST TRANSITION MATERIAL

Test Conditions					Effective Head in Feet	Time of Flow in Hours	Quantity of Flow in CC per Min.	Material Washed Out	
Transition Material		Core Material		Weight in Grams				M.A. Plate ⁴ Curve No.	
Weight in Grams	Height in Inches	Weight in Grams	Height in Inches Initial Final						
10,890	7	--	--	--	0.02	1	31,800	0	-
10,890	7	4000 ^a	2.00	0.75	0.63	2	1,090	234	G
10,890	7	4000	0.75	0.25	1.00	4	3,650	69	H
10,890	7	6000 ^b	1.25	1.25	1.50	3	1.00	61	-
			1.25	1.25		40	3.40	0	-
			1.25	1.25		43	3.10	0	I
10,890	7	6000	1.25	1.25	3.00	4	5.30	-	-
			1.25	1.25		22	3.80	-	-
			1.25	1.25		46	4.50	41	J
10,890	7	6000	1.25	1.25	6.00	5	16.00	-	-
			1.25	1.25		6	14.00	-	-
			1.25	1.25		24	15.00	0	-
10,890	7	8000 ^c	2.50	2.50	6.00	15	11.00	-	-
			2.50	2.50		32	6.00	16	K
			2.50	2.50		128	3.80	24	L

Notes:

Transition material loaded into permeameter under water at a dry density of 114 lb per cu ft.

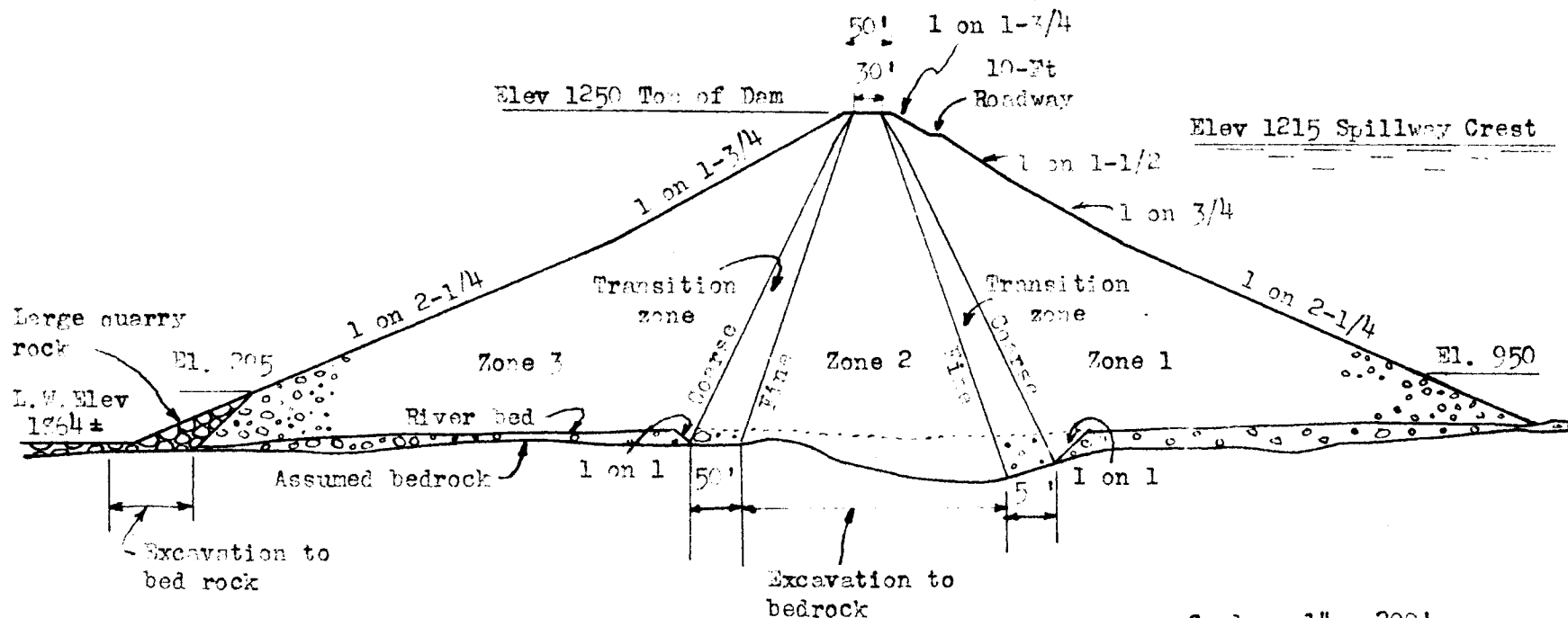
^a 4000 grams of core material gently tamped under water, leaving a 2-in. layer above the transition.
No density determination could be made, because of fines filtering into the transition material.

^b 2000 grams of core material added to existing core.

^c 2000 grams of additional core material added.

Figures shown under height of core material indicate the height of core material above the transition material.

PLATES



Scale: 1" = 200'

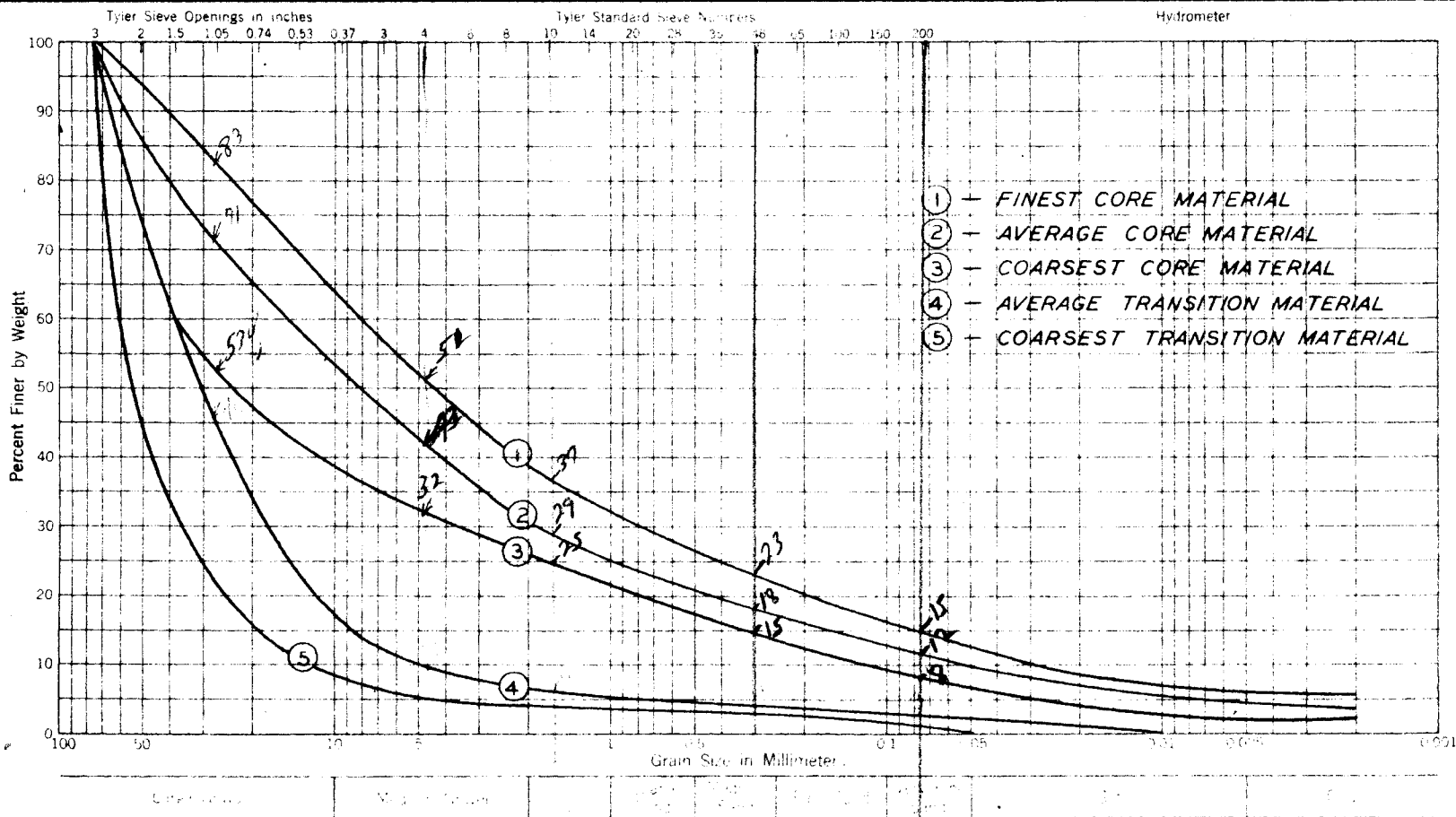
- Zone 1 - Dumped quarry rock sluiced with 1-1/2 cu yd water per cu yd rock.
- Zone 2 - Rolled impervious core. Mixture of sand, gravel, and unaltered till.
- Zone 3 - Dumped quarry rock sluiced with 1-1/2 cu yd water per cu yd rock

Waterways Experiment Station
Filter Investigation, Mud Mountain Dam

CROSS SECTION OF DAM

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Plate 3002-1

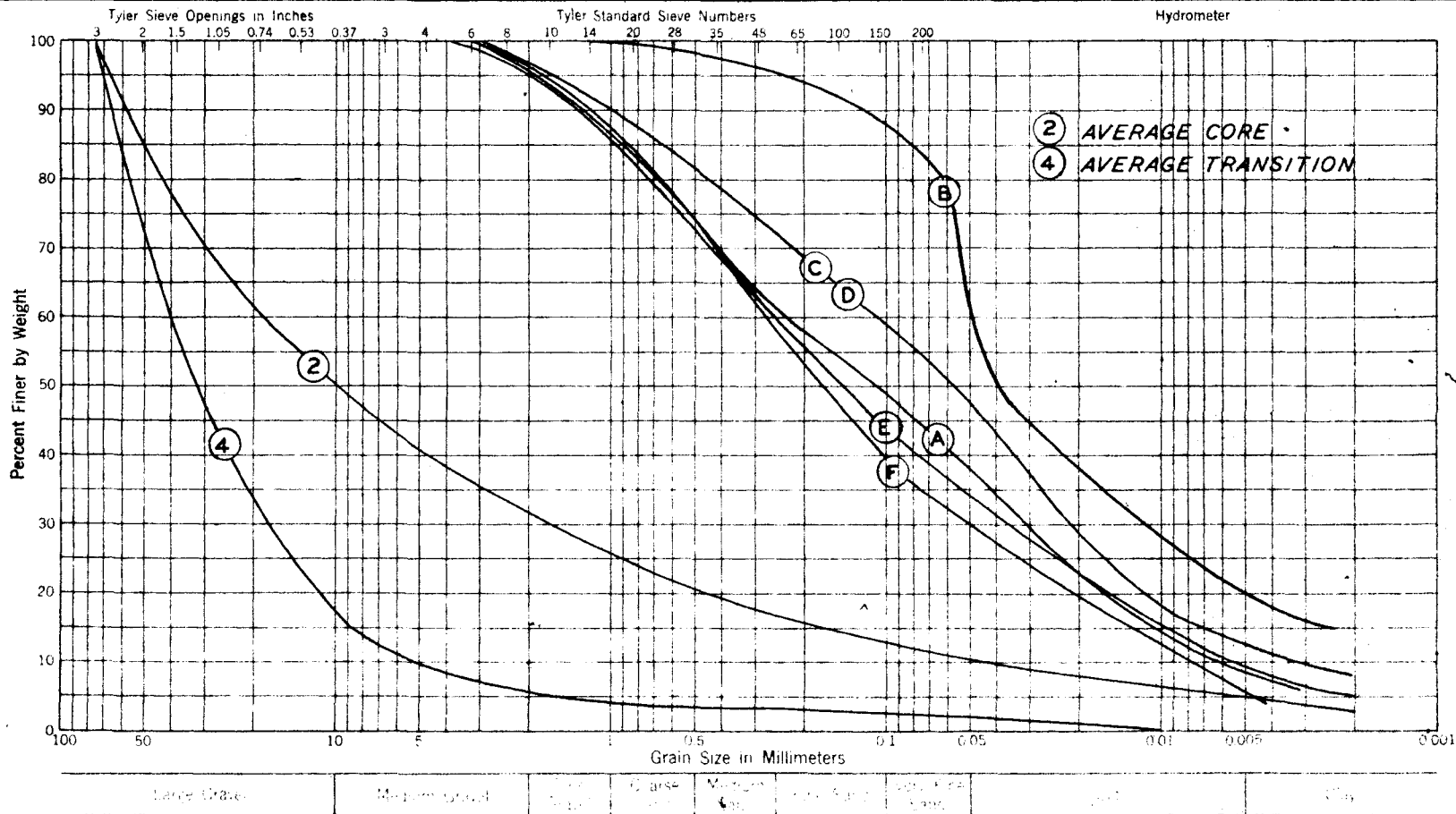


Waterways Experiment Station
Filter Stability Tests, Mud Mountain Dam

GRADATION CURVES - CORE AND TRANSITION MATERIALS

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Plate 3002-2

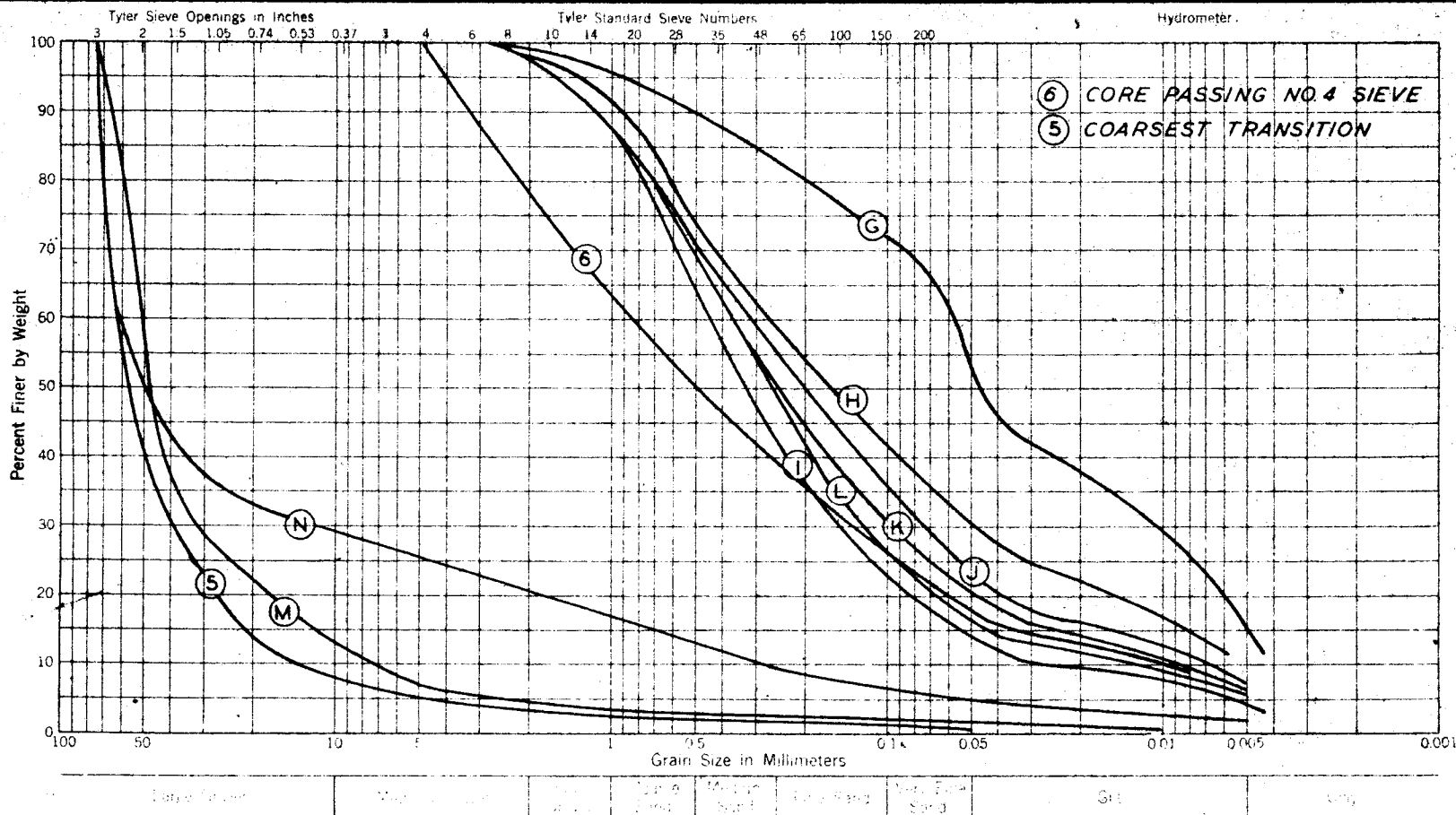


Waterways Experiment Station
Filter Stability Tests, Mud Mountain Dam

GRADATION OF MATERIALS IN FILTER TESTS LISTED IN TABLE 1

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Plate 3002-3



Waterways Experiment Station
Filter Stability Tests, Mud Mountain Dam

GRADATION OF MATERIALS IN STABILITY TESTS LISTED IN TABLE 2

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Plate 3002-4